Earth-Science Reviews 160 (2016) 19–42

Contents lists available at ScienceDirect

Earth-Science Reviews

journal homepage: www.elsevier.com/locate/earscirev

Invited review

Using multi-tracer inference to move beyond single-catchment ecohydrology

Benjamin W. Abbott [a,*], Viktor Baranov [b], Clara Mendoza-Lera [c], Myrto Nikolakopoulou [d], Astrid Harjung [e], Tamara Kolbe [f], Mukundh N. Balasubramanian [g], Timothy N. Vaessen [h], Francesco Ciocca [i], Audrey Campeau [j], Marcus B. Wallin [j], Paul Romeijn [k], Marta Antonelli [l], José Gonçalves [m], Thibault Datry [c], Anniet M. Laverman [a], Jean-Raynald de Dreuzy [f], David M. Hannah [k], Stefan Krause [k], Carolyn Oldham [n], Gilles Pinay [a]

[a] Université de Rennes 1, OSUR, CNRS, UMR 6553 ECOBIO, Rennes, France
[b] Leibniz-Institute of Freshwater Ecology and Inland Fisheries, Germany
[c] Irstea, UR MALY, Centre de Lyon-Villeurbanne, F-69616 Villeurbanne, France
[d] Naturalea, Spain
[e] University of Barcelona, Spain
[f] OSUR-Géosciences Rennes, CNRS, UMR 6118, Université de Rennes 1, France
[g] BioSistemika Ltd., Ljubljana, Slovenia
[h] Centre d'Estudis Avançats de Blanes, Consejo Superior de Investigaciones Científicas (CEAB-CSIC), Girona, Spain
[i] Silixa, UK
[j] Department of Earth Sciences, Uppsala University, Sweden
[k] School of Geography, Earth & Environmental Sciences, University of Birmingham, UK
[l] LIST - Luxembourg Institute of Science and Technology
[m] National Institute of Biology, Slovenia
[n] Civil, Environmental and Mining Engineering, The University of Western Australia, Perth, Australia

ARTICLE INFO

Article history:
Received 1 April 2016
Received in revised form 18 June 2016
Accepted 23 June 2016
Available online xxxx

Keywords:
Hydrological tracer
Water
Environmental hydrology
Flowpath
Residence time
Exposure time
Reactive transport
GW-SW interactions
Hot spots
Hot moments
Damköhler
Péclet
HotDam
Ecohydrology
Crossed proxies
Tracer
Groundwater
Surface water
Aquatic ecology

ABSTRACT

Protecting or restoring aquatic ecosystems in the face of growing anthropogenic pressures requires an understanding of hydrological and biogeochemical functioning across multiple spatial and temporal scales. Recent technological and methodological advances have vastly increased the number and diversity of hydrological, biogeochemical, and ecological tracers available, providing potentially powerful tools to improve understanding of fundamental problems in ecohydrology, notably: 1. Identifying spatially explicit flowpaths, 2. Quantifying water residence time, and 3. Quantifying and localizing biogeochemical transformation. In this review, we synthesize the history of hydrological and biogeochemical theory, summarize modern tracer methods, and discuss how improved understanding of flowpath, residence time, and biogeochemical transformation can help ecohydrology move beyond description of site-specific heterogeneity. We focus on using multiple tracers with contrasting characteristics (crossing proxies) to infer ecosystem functioning across multiple scales. Specifically, we present how crossed proxies could test recent ecohydrological theory, combining the concepts of hotspots and hot moments with the Damköhler number in what we call the HotDam framework.

* Corresponding author.
E-mail address: benabbo@gmail.com (B.W. Abbott).

http://dx.doi.org/10.1016/j.earscirev.2016.06.014

Contents

1. Introduction

"*The waters of springs taste according to the juice they contain, and they differ greatly in that respect. There are six kinds of these tastes which the worker usually observes and examines: there is the salty, the nitrous, the aluminous, the vitrioline, the sulfurous and the bituminous…Therefore the industrious and diligent man observes and makes use of these things and thus contributes to the common welfare.*"

[Georgius Agricola, *De Re Metallica* (1556)]

The central concerns of ecohydrology can be summarized in three basic questions: where does water go, how long does it stay, and what happens along the way (Fig. 1). Answering these questions at multiple spatial and temporal scales is necessary to quantify human impacts on aquatic ecosystems, evaluate effectiveness of restoration efforts, and detect environmental change (Kasahara et al., 2009; Krause et al., 2011; McDonnell and Beven, 2014; Spencer et al., 2015). Despite a proliferation of catchment-specific studies, numerical models, and theoretical frameworks (many of which are detailed and innovative) predicting biogeochemical and hydrological behavior remains exceedingly difficult, largely limiting ecohydrology to single-catchment science (Krause et al., 2011; McDonnell et al., 2007; Pinay et al., 2015).

A major challenge of characterizing watershed functioning is that many hydrological and biogeochemical processes are not directly observable due to long timescales or inaccessibility (e.g. groundwater

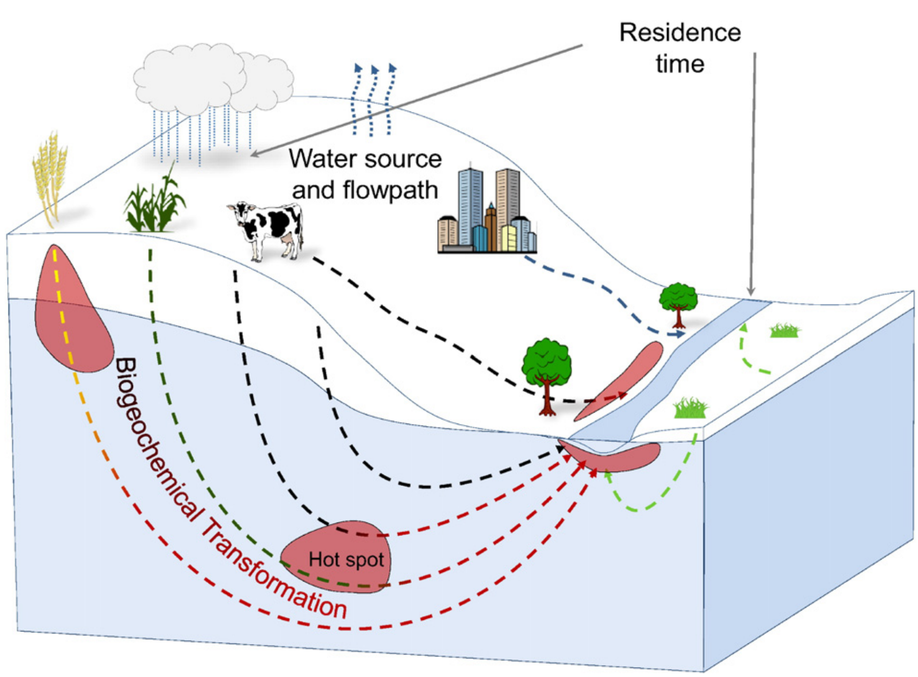

Fig. 1. Conceptual model of a catchment showing the three basic questions of ecohydrology: where does water go, how long does it stay there, and what happens along the way? Dashed lines represent hydrological flowpaths whose color indicates water source and degree of biogeochemical transformation of transported solutes and particulates. The proportion of residence time spent in biogeochemical hot spots where conditions are favorable for a process of interest (McClain et al., 2003) is defined as the exposure time, which determines the retention and removal capacity of the catchment in the HotDam framework (Oldham et al., 2013; Pinay et al., 2015).